WAVECREST Corporation

What is FFT N-clock and 1-clock?

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Introduction

In jitter spectral analysis with *WAVECREST'S* *VISI* software, two visualization options are available known as FFT 1-clk and FFT N-clk. These two spectrums are fundamentally different and often misunderstood. They are defined as the following:

FFT 1-clk is the spectrum of edge-to-edge jitter measured over one clock cycle.

FFT N-clk is the spectrum of jitter measured against a conceptual ideal clock.

The FFT 1-clk basis is generally used for source synchronous applications. The FFT N-clk basis primarily is used for datacom applications.

The architecture of *WAVECREST'S* time interval analyzers (DTS and SIA series) is designed to perform edge-to-edge jitter measurements. Therefore, according to the above definition, all measurements acquired by *WAVECREST* instruments are 1-clk measurements in the time domain. In the *VISI* software, the relationship between FFT N-clk and FFT 1-clk spectra is given by the following:

Eq. 1 $$T_{N-clk(p-p)}(\omega)=\frac{T_{1-clk(peak)}(\omega)}{\pi}\frac{f_c}{f},$$

where $T_{N\text{-}clk(p\text{-}p)}$ is the peak-to-peak FFT N-clk jitter spectrum, $T_{1\text{-}clk(peak)}$ is the peak FFT 1-clk jitter spectrum, f_c is the signal carrier frequency, and f is the frequency of the jitter.

Theory

The relationship given in Eq. 1 can be derived by considering the definitions of N-clk and 1-clk. Fig. 1 shows a clock signal with transition edges at certain times.

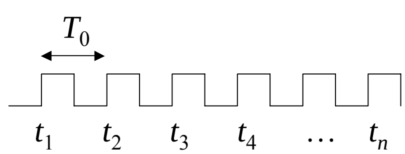

Figure 1 – Timing of clock edges

Let t_n be the time at which the n^{th} clock edge occurs. Note that t_n is not a measurement, but rather the time at which the transition happens. The ideal clock period is T_0. The 1-clk time interval measurements are given by:

Eq. 2 $$t_{1-clk}(n)=t_n-t_{n-1}.$$

Similarly, the N-clk time interval measurements are given by:

Eq. 3 $$t_{N-clk}(n)=t_n-nT_0.$$

Substituting Eq. 3 into Eq. 2, we get

Eq. 4 $$t_{1-clk}(n)=\left[t_{N-clk}(n)+nT_0\right]-\left[t_{N-clk}(n-1)+(n-1)T_0\right].$$

Simplifying, we get

Eq. 5 $$t_{1-clk}(n)=t_{N-clk}(n)-t_{N-clk}(n-1)+T_0 .$$

Let $\Delta n = n\text{-}(n\text{-}1)$ and $\Delta t_{N\text{-}clk} = t_{N\text{-}clk}(n)\text{-}t_{N\text{-}clk}(n\text{-}1)$. Eq. 5 becomes

Eq. 6 $$t_{1-clk}(n)=\frac{\Delta t_{N-clk}(n)}{\Delta n}+T_0 .$$

For timing phenomenon with timescales much greater than T_0, we can approximate the finite differences as derivatives, which gives us

Eq. 7 $$t_{1-clk}\approx\frac{dt_{N-clk}}{dn}+T_0 .$$

This approximation has an error of <2% for jitter frequencies lower than $0.1f_c$. For frequencies greater than $0.1f_c$, correction terms are necessary.

Noting that any length of time can be expressed as a multiple (integer or real) of a clock period, we get the identity $t = nT_0$ and $dt = T_0\ dn$. Applying the chain rule to dn, we get

Eq. 8 $$t_{1-clk}=\frac{dt_{N-clk}}{dt}T_0+T_0 .$$

We perform a Fourier transform on Eq. 8 after removing the constant offset of T_0. Recall that the Fourier transform of a time derivative introduces a factor of $-i\omega$, where i is the imaginary unit and ω is angular frequency. The Fourier spectrum for 1-clk is

Eq. 9 $$T_{1-clk(peak)}(\omega)=-i\omega T_0 T_{N-clk(peak)}(\omega).$$

Substituting $T_0 = 1/f_c$, $\omega = 2\pi f$, solving for $T_{N\text{-}clk}$, and taking the absolute value, we get

Eq. 10 $$T_{N-clk(peak)}(f)=\frac{T_{1-clk(peak)}(f)}{2\pi}\frac{f_c}{f} .$$

Following convention, we express $T_{1\text{-}clk}$ as a peak value and $T_{N\text{-}clk}$ as a peak-to-peak value, which gives us

Eq. 11 $$T_{N-clk(p-p)}(f)=\frac{T_{1-clk(peak)}(f)}{\pi}\frac{f_c}{f} ,$$

and is identical to Eq. 1.

Discussion

We see from Eq. 11 that the N-clk spectrum has a $1/f$ dependence relative to the 1-clk spectrum. Thus, if the N-clk jitter spectrum is flat (white), the 1-clk jitter spectrum is linear with f (+20 dB/decade). Similarly, if the 1-clk jitter spectrum is white, the N-clk spectrum exhibits a $1/f$ (-20 dB/decade) response. In other words, the FFT N-clk spectrum is always more sensitive to low frequency jitter than the FFT 1-clk spectrum.

Fig. 2 shows a sample FFT 1-clk spectrum that has a linear dependence with f. Fig. 3 shows the corresponding FFT N-clk spectrum with flat response.

Because of this relationship, periodic jitter (PJ) spikes have different amplitudes in the two representations. For example, in Fig. 2 we see 1-clk PJ of ~300 fs at 100 MHz and ~0.7 ps at 300 MHz. However, in Fig. 3 we see the same PJ in the N-clk basis is ~0.8 ps at both 100 MHz and 300 MHz. Therefore, when comparing levels PJ, it is important to specify their basis.

Also, note that many of *VISI's* tools (such as histograms) are constructed with 1-clk measurements and should only be correlated with the FFT 1-clk spectrum. Similarly, spectra acquired with a spectrum analyzer should only be correlated with the FFT N-clk spectrum.

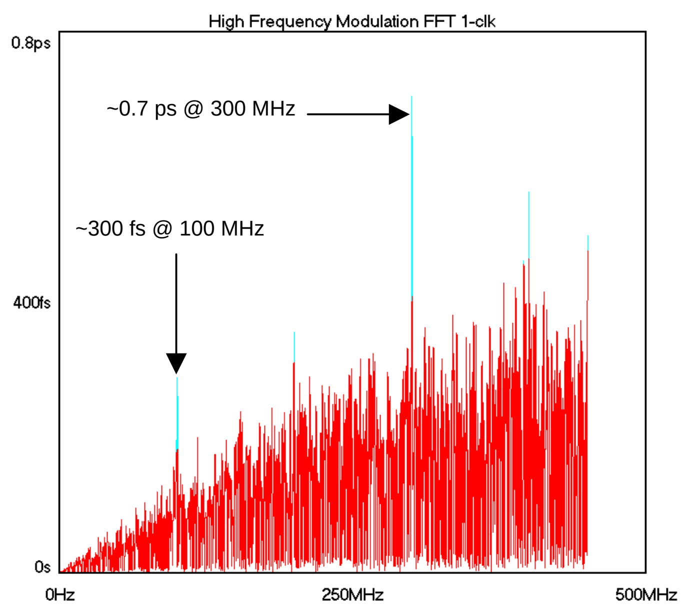

Figure 2 - Sample FFT 1-clk spectrum with prominent PJ at 100 MHz and 300 MHz.

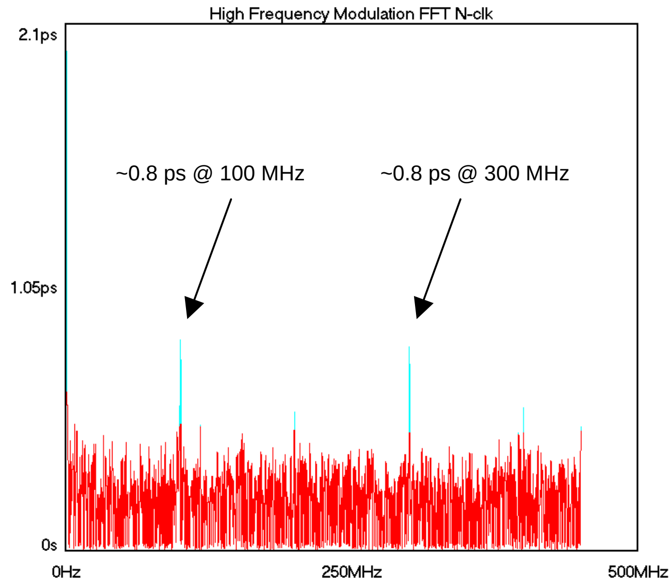

Figure 3 - Sample FFT N-clk spectrum with prominent PJ at 100 MHz and 300 MHz

Adjacent Cycle Jitter (JEDEC Cycle-to-cycle Jitter)

We can further expand our understanding of N-clk and 1-clk jitter to include Adjacent Cycle jitter. Adjacent Cycle jitter (also referred to by JEDEC as "cycle-to-cycle period jitter" [i]) is the period deviation from one period to the next adjacent period. Using the illustration provided in Figure 1, Adjacent Cycle jitter is given by:

Eq. 12
$$\begin{aligned} t_{Adj-Cy}(n) &= (t_{n+1} - t_n) - (t_n - t_{n-1}) \\ &= t_{1-clk}(n+1) - t_{1-clk}(n) \end{aligned}.$$

Following a similar argument as in the Theory section, we find the Adjacent Cycle jitter equivalent to the first time derivative of 1-clk jitter (and second time derivative of N-clk jitter),

Eq. 13
$$t_{Adj-Cy} = \frac{dt_{1-clk}}{dt} T_0 .$$

As before, Eq.13 is valid for $f < 0.25 f_c$. In the frequency domain, Eq.13 becomes

Eq. 14
$$T_{1-clk(peak)}(f) = \frac{T_{Adj-Cy(peak)}(f)}{2\pi} \frac{f_c}{f},$$

where $T_{Adj\text{-}Cy}$ is the Adjacent Cycle jitter spectrum. Substituting Eq.14 into Eq.1 gives us the relationship between Adjacent Cycle jitter spectra and N-clk jitter spectra, Eq. 15 $$T_{N-clk(p-p)}(f) = \frac{T_{Adj-Cy(peak)}(f)}{2\pi^2}\left(\frac{f_c}{f}\right)^2 .$$

where $T_{N\text{-}clk}$ is a peak-to-peak value, and both $T_{1\text{-}clk}$ and $T_{Adj\text{-}Cy}$ are peak values.

Summary and Conclusions

A simple relationship between FFT N-clk and FFT 1-clk is given in Eq. 1. We identified the N-clk jitter to be absolute, while 1-clk jitter is relative to an earlier transition edge. We proved that 1-clk jitter is equivalent to the first time derivative of N-clk jitter.

WAVECREST instruments only perform edge-to-edge (1-clk) measurements to prevent trigger jitter. However, we can exploit the properties of Fourier transforms to find the N-clk spectrum despite being limited to 1-clk jitter measurements.

Furthermore, we identified Adjacent Cycle jitter (JEDEC cycle-to-cycle period jitter) as the first time derivative of 1-clk jitter (and second time derivative of N-clk jitter). Following a similar derivation, we relate Adjacent Cycle jitter to 1-clk and N-clk jitter in Eq. 14 and Eq. 15, respectively.

In conclusion, many applications have different definitions of jitter. This technical bulletin describes and relates the differences between Adjacent Cycle jitter, edge-to-edge jitter and edge-to-ideal clock jitter. *WAVECREST* continues to expand its expertise in jitter measurements and analysis, providing comprehensive solutions to timing issues.

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[i] *JEDEC Standard, Definition of Skew Specifications for Standard Logic Devices* (JESD65-A), JEDEC Solid State Technology Association (2001).

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